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(54) **METHODS OF FORMING PACKAGED SEMICONDUCTOR LIGHT EMITTING DEVICES HAVING FRONT CONTACTS BY COMPRESSION MOLDING**

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B29C 43/18	(2006.01)
B29C 33/00	(2006.01)
B29L 11/00	(2006.01)
H01L 33/52	(2010.01)
B29C 33/02	(2006.01)

(52) **U.S. Cl.**

CPC ***B29C 43/021*** (2013.01); *B29C 33/0022* (2013.01); ***B29C 43/18*** (2013.01); *B29L 2011/0016* (2013.01); *H01L 33/52* (2013.01); *H01L 2224/48091* (2013.01); *H01L 2224/48227* (2013.01); *H01L 2924/01068* (2013.01); *H01L 2924/3011* (2013.01); *B29C 33/02* (2013.01)

(58) **Field of Classification Search**

USPC 257/98, 95, 89, 79, 77, 76, 676, 433, 257/103, 100, 82; 438/107, 22, 27, 33, 39, 438/45, 29, 26

See application file for complete search history.

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Primary Examiner — Errol Fernandes

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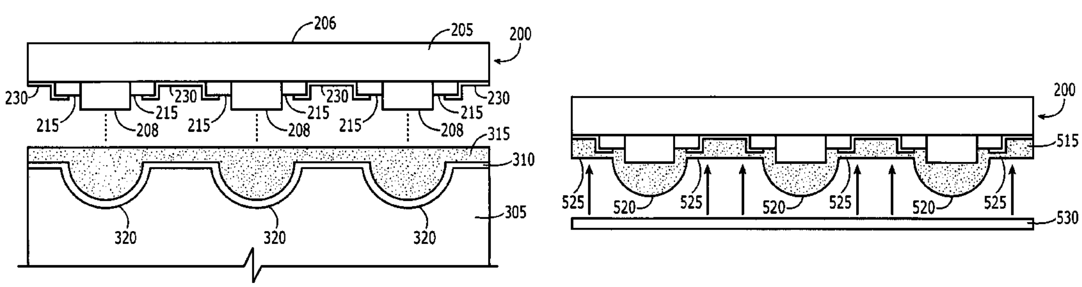
(57) **ABSTRACT**

Methods of packaging a semiconductor light emitting device include providing a substrate having the semiconductor light emitting device on a front face thereof and a contact on a front face thereof, wherein the light emitting device is electrically connected to the contact on the front face of the substrate. The substrate is compression molded to form an optical element on the front face of the substrate over the semiconductor light emitting device and a residual coating over a region of the front face of the substrate including the contact. The residual coating over the contact may be removed without damaging the contact. Packaged semiconductor light emitting devices are also provided.

22 Claims, 5 Drawing Sheets



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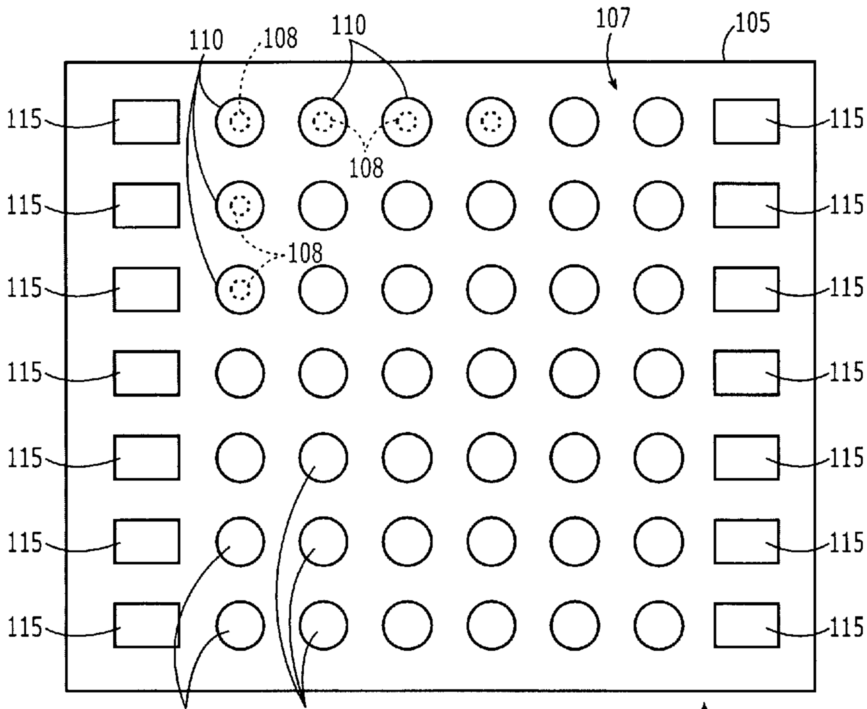
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FIG. 1

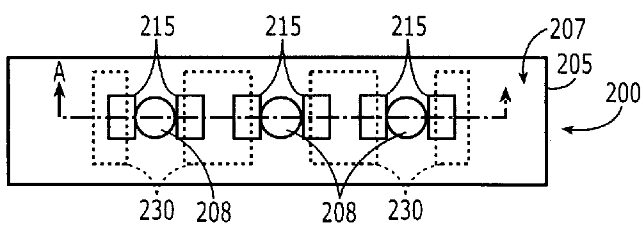
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FIG. 2

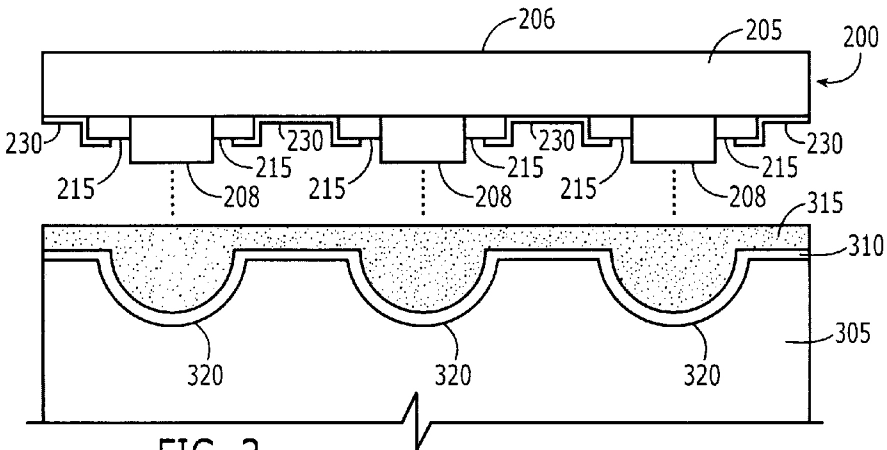

FIG. 3

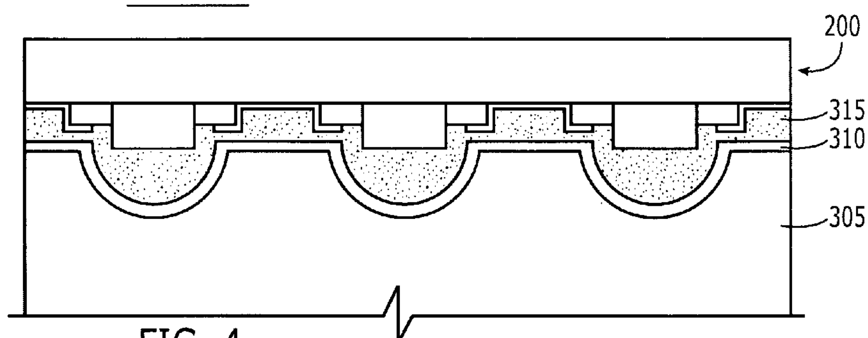

FIG. 4

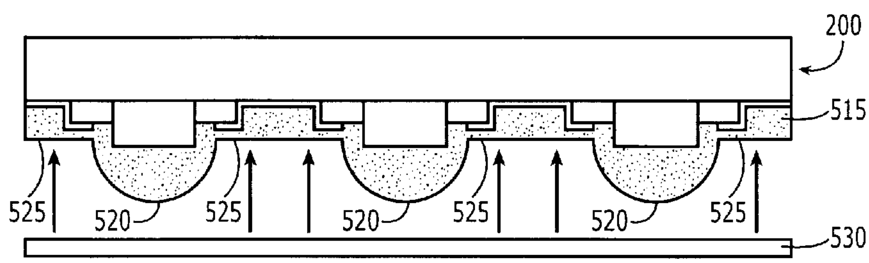

FIG. 5

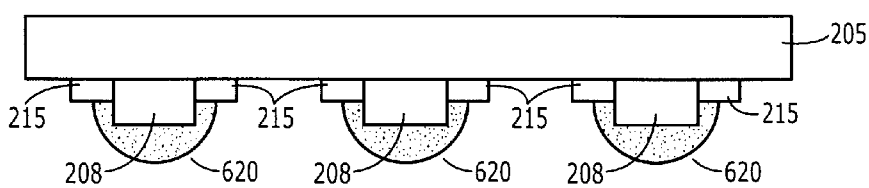

FIG. 6

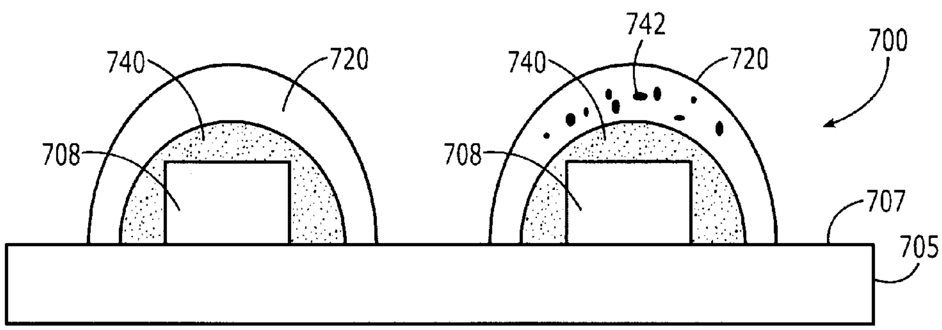

FIG. 7

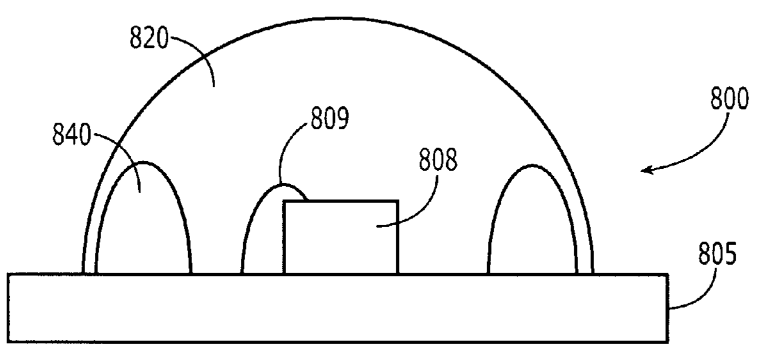

FIG. 8

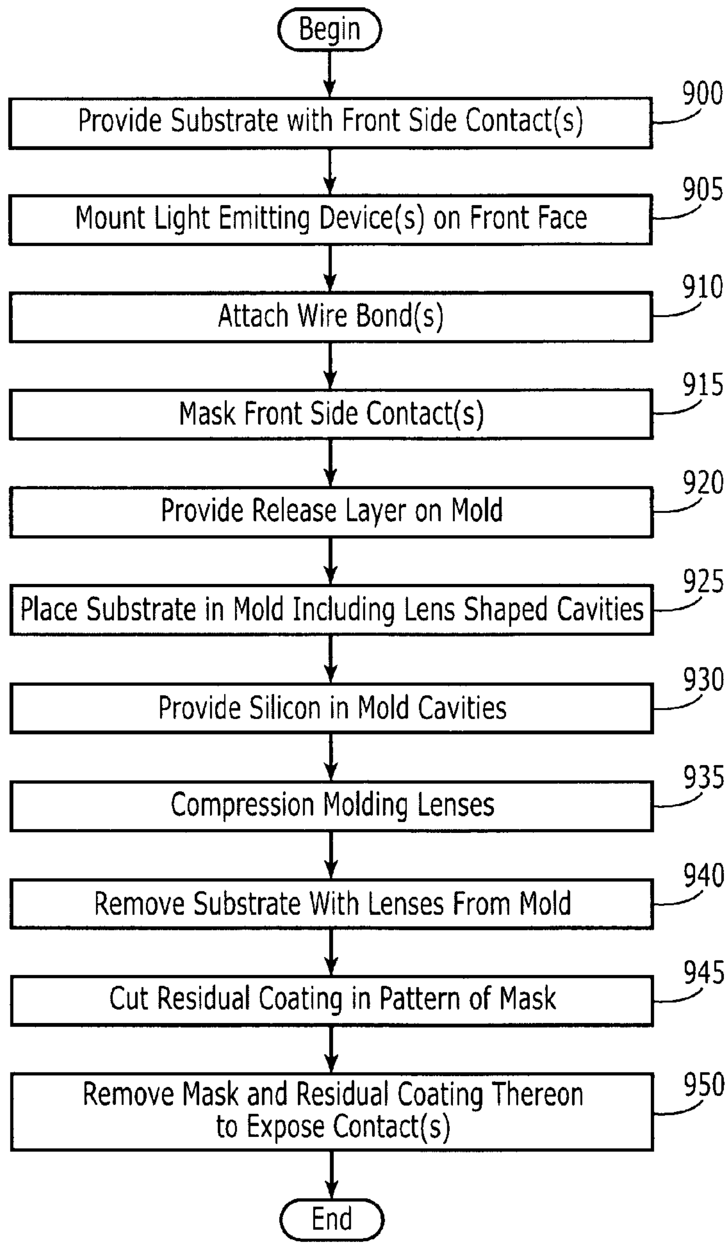
Begin
Provide Substrate with Front Side Contact(s)
900
Mount Light Emitting Device(s) on Front Face
905
Attach Wire Bond(s)
910
Mask Front Side Contact(s)
915
Provide Release Layer on Mold
920
Place Substrate in Mold Including Lens Shaped Cavities
925
Provide Silicon in Mold Cavities
930
Compression Molding Lenses
935
Remove Substrate With Lenses From Mold
940
Cut Residual Coating in Pattern of Mask
945
Remove Mask and Residual Coating Thereon to Expose Contact(s)
950
End

FIG. 9

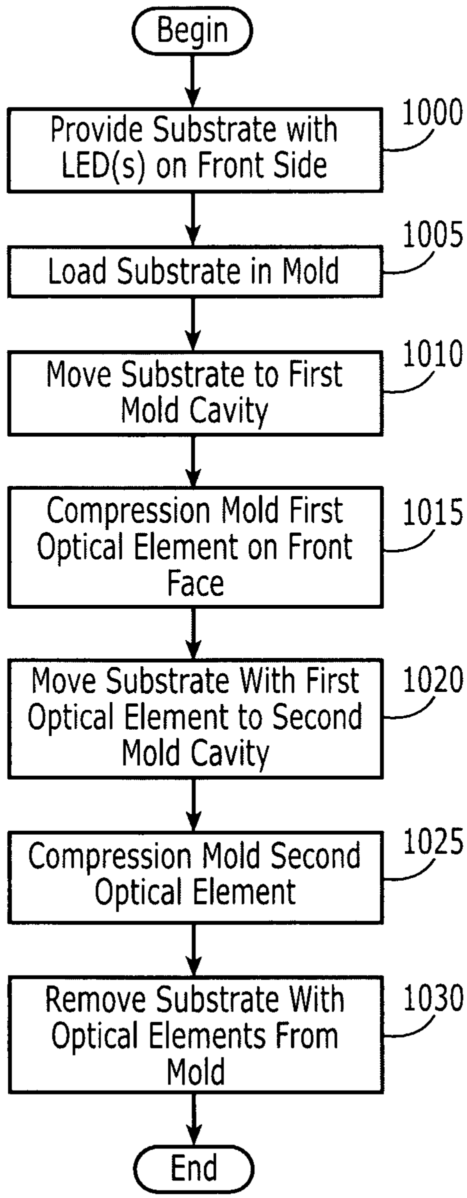
Begin
Provide Substrate with LED(s) on Front Side
1000
Load Substrate in Mold
1005
Move Substrate to First Mold Cavity
1010
Compression Mold First Optical Element on Front Face
1015
Move Substrate With First Optical Element to Second Mold Cavity
1020
Compression Mold Second Optical Element
1025
Remove Substrate With Optical Elements From Mold
1030
End

FIG. 10

METHODS OF FORMING PACKAGED SEMICONDUCTOR LIGHT EMITTING DEVICES HAVING FRONT CONTACTS BY COMPRESSION MOLDING

BACKGROUND OF THE INVENTION

This invention relates to semiconductor light emitting devices and manufacturing methods therefor, and more particularly to packaging and packaging methods for semiconductor light emitting devices.

Semiconductor light emitting devices, such as Light Emitting Diodes (LEDs) or laser diodes, are widely used for many applications. As is well known to those having skill in the art, a semiconductor light emitting device includes one or more semiconductor layers that are configured to emit coherent and/or incoherent light upon energization thereof. It is also known that the semiconductor light emitting device generally is packaged to provide external electrical connections, heat sinking, lenses or waveguides, environmental protection and/or other functions.

For example, it is known to provide a two-piece package for a semiconductor light emitting device, wherein the semiconductor light emitting device is mounted on a substrate that comprises alumina, aluminum nitride and/or other materials, which include electrical traces thereon, to provide external connections for the semiconductor light emitting device. A second substrate, which may comprise silver plated copper, is mounted on the first substrate, for example, using glue, surrounding the semiconductor light emitting device. A lens may be placed on the second substrate over the semiconductor light emitting device. Light emitting diodes with two-piece packages as described above are described in Application Serial No. US 2004/0041222 A1 to Loh, entitled Power Surface Mount Light Emitting Die Package, published Mar. 4, 2004, assigned to the assignee of the present invention, the disclosure of which is hereby incorporated herein by reference in its entirety as if set forth fully herein.

With multipart mounting packages for semiconductor light emitting devices, the different parts are typically made of different materials. As a result, the thermal impedance for such packages may be higher and a thermal mismatch may result among the various components within a package that may cause reliability problems with a package. For example, problems may result at an interface between a copper metal of a heat sink or cavity with a plastic of a body in which such a heat sink or cavity is mounted. In addition, assembly may be more complicated because of increased piece part counts for the package. In addition, where a sheet metal optical cavity is utilized, a cavity typically can only be fabricated in a limited range of depth and shape configurations. Such multipart packages may also have a larger optical cavity space, resulting in greater volumes of encapsulant being used, which may increase problems related to delamination and/or formation of bubbles within the encapsulant during temperature cycles.

The use of a pre-molded lens attached by adhesive may encounter some problems in robustness and reliability of the finished product. For example, the manufacturing process for such devices may be inherently inconsistent and the resultant package may be less robust and/or reliable. It is also known to form the lens using a dispensing method capitalizing on the viscosity of a resin used in forming the lens.

In some applications, it may be preferred to mount the LED on a surface of a substrate, such as a ceramic substrate, a metal core printed circuit board (MCPCB), a flexible circuit substrate and/or a lead frame, without use of a reflector cup. However, where no such structure is provided, it may be more

difficult to form and/or secure a lens as various of the approaches described above may not be well suited to use where the LED is not positioned within a cavity.

It is also known to use transfer molding of epoxy to encapsulate certain low power LED packages, such as miniature surface mountable devices available from from Hewlett Packard Corporation. The epoxy on such devices may provide the structural strength to the package as well as encapsulating the devices inside. However, epoxy tends to be degraded by the electromagnetic energy of blue light, generally generated by some semiconductor light emitting devices, and may become less transmissive to light as a result. The resulting package may, therefore, become dimmer over a relatively short period of time. As such, epoxy may be a less attractive option for encapsulating devices that emit blue light. In addition, epoxy generally has a Coefficient of Thermal Expansion (CTE) mismatch problem with silicone soft gel, which may be used to junction coat the LED chips and their bond wires as the first layer of encapsulant.

It is also known to use casting to encapsulate LED devices with epoxy. This process typically can only be applied to an open chamber, where curing may occur with the epoxy contained in a cup and a lead frame may be inserted inside the cup and be casted when the epoxy is cured. During curing, a level of liquid epoxy is generally free to adjust itself as a result of chemical reactions and shrinkage in volume.

Another approach uses compression molded lenses formed of silicone. Using compression molding, an array of compression molded lenses may be placed over a matching array of LED chips on a substrate or wafer. However, conventional compression molding of lenses generally requires the use of electrical contacts on the back side, rather than the front side, of the substrate as the molding material may extend across and limit formation of electrical connections with front side contacts.

Packaging of semiconductor light emitting devices may add cost to the resulting packaged device due to the precision required for various operations. The costs typically increase as packaged light emitting devices having different optical properties are required. While compression molding technology has been proposed that could lower the cost for forming packaged light emitting devices, benefits of this technology have not been fully realized. For example, such techniques have generally only been used to produce simple lenses made of one material.

SUMMARY OF THE INVENTION

Some embodiments of the present invention provide methods of packaging a semiconductor light emitting device, including providing a substrate having the semiconductor light emitting device on a front face thereof and a contact on a front face thereof, wherein the light emitting device is electrically connected to the contact on the front face of the substrate. An optical element is compression molded on the front face of the substrate over the semiconductor light emitting device and a residual coating may be concurrently compression molded over a region of the front face of the substrate including the contact. The residual coating over the contact may be removed without damaging the contact.

In other embodiments, providing a substrate includes mounting the semiconductor light emitting device on the front face of the substrate and attaching a wire bond electrically connecting the semiconductor light emitting device to a contact portion of the substrate. A second semiconductor light emitting device may be mounted on a back face of the substrate and electrically connected to a contact on the back face of the substrate. Compression molding the optical element may include forming the optical element over the semiconductor light emitting device and the wire bond and directly contacting the wire bond. The substrate may be a ceramic substrate, a metal core printed circuit board (MCPCB), a flexible circuit substrate and/or a lead frame.

In further embodiments, compression molding the optical element is preceded by providing a mask covering the front side contact and removing the residual coating includes removing the mask. The mask may be a polyimide film. Removing the mask may include cutting the residual coating in a pattern corresponding to the mask and removing the mask and the overlaying residual coating thereon to expose the front side contact.

In other embodiments, the substrate includes a plurality of semiconductor light emitting devices and contacts on the front face thereof and compression molding the optical element includes forming a plurality of optical elements on the front face of the substrate over corresponding ones of the semiconductor light emitting devices and a residual coating over a region of the front face of the substrate including the plurality of contacts. For example, cutting the residual coating may include cutting the residual coating with a hot knife and/or wire mesh. The hot knife and/or wire mesh may have a pattern corresponding to the pattern cut in the residual coating.

In further embodiments, the optical elements comprise lenses and compression molding includes placing the substrate in a mold including a plurality of lens shape cavities positioned proximate corresponding ones of the plurality of semiconductor light emitting devices, providing silicone into the mold, compression molding the lenses from the silicone in the cavities and removing the substrate with the lenses formed therein from the mold. Providing silicone may be preceded by providing a release layer on a surface of the mold including the cavities and removing the substrate may include removing the substrate at the release layer.

In yet other embodiments, the substrate is a flexible circuit substrate and removing the residual coating includes wet solvent chemical cleaning the substrate to remove the residual coating over the contact. Removing the residual coating may be performed using a laser, mechanical saw and/or the like in some embodiments.

In further embodiments, the optical element is a first and a second optical element and compression molding the optical element includes compression molding the first optical element proximate the semiconductor light emitting device and compression molding the second optical element over the semiconductor light emitting device and the first optical element. Compression molding the first optical element may include compression molding the first optical element over the semiconductor light emitting device.

In some embodiments compression molding the optical element is preceded by forming a first optical element proximate the semiconductor light emitting device and compression molding the optical element includes compression molding a second optical element over the semiconductor light emitting device and the first optical element.

In yet further embodiments of the present invention, packaged semiconductor light emitting devices include a substrate having a contact on a front face thereof. A semiconductor light emitting device is mounted on the front face of the substrate. A compression molded optical element is on the front face of the substrate over the semiconductor light emitting device.

In further embodiments, the semiconductor light emitting device is mounted flush on the front face of the substrate without a reflector cavity and the optical element is molded to and extends from the front face of the substrate in a region surrounding the semiconductor light emitting device and extends over the semiconductor light emitting device. The optical element may be a second optical element and the device may further include a first optical element positioned proximate the semiconductor light emitting device and the second optical element may extend over the first optical element. The first optical element may be a compression molded optical element. The compression molded optical element may be a silicone lens. The second optical element may be a lens having different optical properties than the first optical element. For example, the second optical element may have a phosphor or other light scattering, luminescent and/or diffusing material therein.

In other embodiments, the semiconductor light emitting device is a plurality of semiconductor light emitting devices and the contact is a plurality of contacts on the front face. The compression molded optical element is a plurality of compression molded optical elements over corresponding ones of the semiconductor light emitting devices.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a top plan view of a packaged semiconductor light emitting device according to some embodiments of the present invention.

FIG. **2** is a top plan view of a packaged semiconductor light emitting device according to further embodiments of the present invention.

FIGS. **3** through **6** are cross sectional views illustrating a method of forming the packaged semiconductor light emitting device of FIG. **2** taken along line A-A of FIG. **2** according to some embodiments of the present invention.

FIG. **7** is a cross sectional view of a packaged semiconductor light emitting device according to other embodiments of the present invention.

FIG. **8** is a cross sectional view of a packaged semiconductor light emitting device according to further embodiments of the present invention.

FIG. **9** is a flow chart illustrating operations for forming a packaged semiconductor light emitting device according to some embodiments of the present invention.

FIG. **10** is a flow chart illustrating operations for forming a packaged semiconductor light emitting device according to other embodiments of the present invention.

DETAILED DESCRIPTION

The invention is described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, the size and relative sizes of layers and regions may be exaggerated for clarity.

It will be understood that when an element or layer is referred to as being “on”, “connected to” or “coupled to” another element or layer, it can be directly on, connected or coupled to the other element or layer or intervening elements or layers may be present. In contrast, when an element is referred to as being “directly on,” “directly connected to” or “directly coupled to” another element or layer, there are no intervening elements or layers present. Like numbers refer to like elements throughout. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

It will be understood that, although the terms first, second, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms are only used to distinguish one element, component, region, layer or section from another region, layer or section. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the present invention.

Spatially relative terms, such as "beneath", "below", "lower", "above", "upper" and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the exemplary term "below" can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

Embodiments of the present invention are described herein with reference to cross-section illustrations that are schematic illustrations of idealized embodiments of the present invention. As such, variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, embodiments of the present invention should not be construed as limited to the particular shapes of regions illustrated herein but are to include deviations in shapes that result, for example, from manufacturing. For example, an etched region illustrated as a rectangle will, typically, have rounded or curved features. Thus, the regions illustrated in the figures are schematic in nature and their shapes are not intended to illustrate the precise shape of a region of a device and are not intended to limit the scope of the present invention.

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and this specification and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

Embodiments of packaged semiconductor light emitting devices and methods for forming the same will now be described with reference to FIGS. **1-9**. Referring first to FIG. **1**, a packaged semiconductor light emitting device **100** is schematically illustrated in top plan view. More particularly the illustrated device **100** is shown as including a substrate **105** having a plurality of semiconductor light emitting devices **108** mounted in array arrangement on a front face **107** of the substrate **105**. A compression molded optical element **110**, shown as a lens, is formed on the front face **107** of the substrate **105** over respective semiconductor light emitting devices **108**.

The semiconductor light emitting device(s) **108** can comprise a light emitting diode, laser diode and/or other device which may include one or more semiconductor layers, which may comprise silicon, silicon carbide, gallium nitride and/or other semiconductor materials, a substrate which may comprise sapphire, silicon, silicon carbide, gallium nitride or other microelectronic substrates, and one or more contact layers which may comprise metal and/or other conductive layers. The design and fabrication of semiconductor light emitting devices are well known to those having skill in the art.

For example, the light emitting device(s) **108** may be gallium nitride based LEDs or lasers fabricated on a silicon carbide substrate such as those devices manufactured and sold by Cree, Inc. of Durham, N.C. For example, the present invention may be suitable for use with LEDs and/or lasers as described in U.S. Pat. Nos. 6,201,262, 6,187,606, 6,120,600, 5,912,477, 5,739,554, 5,631,190, 5,604,135, 5,523,589, 5,416,342, 5,393,993, 5,338,944, 5,210,051, 5,027,168, 5,027,168, 4,966,862 and/or 4,918,497, the disclosures of which are incorporated herein by reference as if set forth fully herein. Other suitable LEDs and/or lasers are described in published U.S. Patent Publication No. US 2003/0006418 A1 entitled Group III Nitride Based Light Emitting Diode Structures With a Quantum Well and Superlattice, Group III Nitride Based Quantum Well Structures and Group III Nitride Based Superlattice Structures, published Jan. 9, 2003, as well as published U.S. Patent Publication No. US 2002/0123164 A1 entitled Light Emitting Diodes Including Modifications for Light Extraction and Manufacturing Methods Therefor. Furthermore, phosphor coated LEDs, such as those described in United States Patent Application No. US 2004/0056260 A1, published on Mar. 25, 2004, entitled Phosphor-Coated Light Emitting Diodes Including Tapered Sidewalls, and Fabrication Methods Therefor, the disclosure of which is incorporated by reference herein as if set forth fully, may also be suitable for use in embodiments of the present invention.

In still other embodiments, a drop of a material such as epoxy that contains phosphor therein may be placed on the semiconductor light emitting device. LEDs that employ phosphor coatings are described, for example, in U.S. Pat. Nos. 6,252,254; 6,069,440; 5,858,278; 5,813,753; 5,277,840; and 5,959,316.

Also shown on the front face **107** of the substrate **105** is a plurality of electrical contacts **115**. For example, the contacts **115** may be gold plated electrical contact pads connecting the semiconductor light emitting devices **108** to electrical circuits, power sources and the like. It will be understood that, while only contacts on the front face **107** are discussed herein, backside contacts may also be provided in some embodiments.

As will be described further herein, methods are provided in certain embodiments of the present invention whereby a compression molded lenses **110** may be formed on front face **107** of the substrate **105** while still using front face contacts **115** and allowing electrical connections to the front face **107** without interference from residual deposits of the non-conductive material used to form the lenses **110**. Furthermore, residual silicone used in forming the lenses **110** may remain on the surfaces of the front face **107** to which no electrical contact is required in some embodiments of the present invention.

It will be understood that the arrangement shown in FIG. **1** is for exemplary purposes and that a variety of different configurations and combinations of one or more semiconductor light emitting devices **108** and contacts **115** may be included in the package semiconductor light emitting device **100** in various embodiments of the present invention, including devices having only a single light emitting device **108**. Similarly, it will be understood that the structure **100** illustrated in FIG. **1** may, in some embodiments, be further processed with portions thereof separated to provide a plurality of discrete packaged semiconductor light emitting devices formed from the illustrated device **100**.

Depending on the embodiments, the substrate can included embedded electrical connections to form a string or cluster of LEDs between electrical contacts **115** to provide individual front side contact LEDs and/or strings or clusters of LEDs. Additionally, the individual LEDs with lenses can each include contacts to enable the LEDs.

Semiconductor light emitting devices **108** may, in some embodiments of the present invention, be mounted flush on the front face **107** on the substrate **105** without a reflector cavity surrounding the light emitting devices **108** as seen, for example, in FIG. **7**.

A packaged semiconductor light emitting device **200** according to further embodiments will now be described with reference to the schematic illustration of FIG. **2**. As shown in the embodiments FIG. **2**, the packaged semiconductor light emitting device **200** includes a substrate **205** and a plurality of light emitting devices **208** mounted flush on a front face **207** of the substrate **205**. A plurality of electrical contacts **215** are shown on the front face **207** proximate the semiconductor light emitting devices **208**. Also shown in FIG. **2** is a mask **230** covering the front side of contacts **215**. As illustrated in FIG. **2**, the mask **230** may not entirely cover the totality of the surface area of the contacts **215**.

The semiconductor light emitting devices **208** are illustrated schematically in FIG. **2** as having a circular shape. However, it will be understood that the shape of the semiconductor light emitting devices **208** may vary and the circular representation is for purposes of describing the present invention. Furthermore, the compression molded lens **110** structures are not shown in FIG. **2**. The particular arrangement of the front side contacts **215** relative to the light emitting devices **208** and the number of front side contacts **215** is for illustrative purposes and other arrangements may be provided in accordance with some embodiments of the present invention.

Methods of forming a packaged semiconductor light emitting device according to some embodiments of the present invention will now be described with reference to the cross-sectional illustrations of FIGS. **3-6** and the flow chart illustration of FIG. **9**. The cross-sectional illustrations of FIGS. **3-6** are taken along the line A-A of FIG. **2**. As such, it will understood that, as with the description of FIG. **2**, the particular arrangement of contacts **215** and light emitting devices **208** in FIGS. **3-6** is for purposes of description of the present invention and the methods of the present invention are not limited to the particular structure or arrangement of components illustrated in the Figures.

As will be described with reference to the Figures, some embodiments of the present invention provide methods for forming packaged semiconductor light emitting devices with molded compression lenses and front face electrical contacts on a substrate. The substrate may be, for example, a ceramic substrate, a metal core printed circuit board (MCPCB), a flex circuit and/or a lead frame. For the embodiments illustrated in FIGS. **3-6**, a mask or stencil, such as a polyimide film, is applied to the contacts on the substrate prior to molding. After the compression molded lenses, such as silicone lenses or the like, are applied to the substrate, a hot screen or other removal method can be used to remove the lens forming material from the front side contacts covered by the mask or stencil. However, it will be understood that further embodiments of the present invention provide manufacturing of packaged semiconductor light emitting devices including compression-molded lenses without the use of a mask or substrate. Also, different types of masks can be used as well as different methods may be used for removing residual lens forming material, such as a laser, saw, hot knife, hot wire grid and/or wire mesh.

As seen in the embodiments illustrated in FIG. **3**, an assembly **200** including a substrate **205** with semiconductor light emitting devices **208** and front side contacts **215** on a front face **207** thereof is provided. As noted above, in the illustrated embodiments, a mask **230** is also provided covering the front side contacts **215**. Also shown schematically in FIG. **3** is a compression mold **305**. Mold **305** is provided with indentations or cavities **320** shaped as lenses. A cavity **320** is provided for each respective one of the illustrated plurality of light emitting devices **208**. Silicone **315** is placed over the mold **305** and in the indentations **320**. As also shown in FIG. **3**, a release layer **310** may also be used between the silicone **315** and the mold **305**. The release layer **310** may facilitate removing the mold **305** at the release layer **310** after compression molding of lenses from the silicone **315**. The release layer **310** may be, for example, Aflex film available from Asahi Glass Company. As seen in FIG. **3**, the silicone **315** in the compression molding process illustrated fills the cavities **320** but further extends across the region between and surrounding the cavities **320**, to correspondingly result in deposition on the substrate **205** of a residual coating over a region of the front face of the substrate **205** including the contact **215**. Such an additional coverage of silicone **315** may occur due to the nature of the compression molding process used to form the lens or optical element in embodiments of the present invention as described herein.

Referring now to FIG. **4**, the assembly **200** is shown inserted in the mold **305** during compression molding of the substrate **205** to form optical elements on a front face of the substrate over the respective semiconductor light emitting devices **208**. In some embodiments, the material used in forming the compression molded optical element and residual coating is a silicone plastic and the compression molding occurs at a temperature of about 100° C. to about 150° C. (or about 140° C. in some embodiments) for a time of about three to about ten minutes (or about five minutes in some embodiments) at a pressure of about 0.1 to about 0.6 tons/in^2. An example of a suitable silicone material for use in forming packaged semiconductor light emitting devices in some embodiments of the present invention is organopolysiloxane mixture.

As seen in FIG. **5**, after compression molding, the mold **305** is removed at the release layer **310**. As such, the assembly **200** includes a compression molded optical element **520** over each of the light emitting devices **208** in addition to a residual coating **525** over a region of the front face of the substrate including the contacts **215**. In other words, the compression molded silicone layer **515** includes both the residual coating **525** and the optical element **520** at the time of removal from the mold **305** as shown in FIG. **5**.

FIG. **5** further illustrates use of a removal method or process used to remove the silicone located on the mask **230** while leaving a molded lens over each light emitting device **208**. As particularly illustrated in FIG. **5**, the removal process includes cutting the residual coating **525** in a pattern corresponding to the mask **230** with a hot knife **530** or other cutting means having a pattern corresponding to the pattern cut into the residual coating **525**. In some embodiments, the hot knife **530** itself has a corresponding pattern, allowing the cutting operation to be executed with a single motion in the direction illustrated by the arrows in FIG. **5** without the need for motion in a second direction. In some other embodiments of the present invention, the cutting apparatus **530** may further make a second or third directional movement to provide for cutting the residual coating **525** as desired to expose an electrical contact portion of the contacts **215** without damaging the contacts **215**.

The resulting packaged semiconductor light emitting device structure after the removal operations illustrated in FIG. **5** according to some embodiments of the present invention is illustrated in FIG. **6**. As seen in FIG. **6**, the substrate **205** includes a plurality of light emitting devices **208** with compression molded lenses **620** formed over corresponding ones of the light emitting devices **208**. The residual coating **525** over a region of the front face of the substrate **205** including a contact area of the contacts **215** has been removed, without damaging the contacts **215**, to allow formation of electrical connections to the contacts **215**.

Operations for forming a semiconductor light emitting device according to further embodiments of the present invention will now be described with reference to the flow chart illustration of FIG. **9**. As shown in embodiments illustrated in FIG. **9**, operations begin at block **900** by providing a substrate **105**, **205** having contacts **115**, **215** on a front face **107**, **207** thereof (block **900**). A semiconductor light emitting device **108**, **208** is mounted on the front face **107**, **207** of the substrate **105**, **205** (block **905**). The light emitting device **108**, **208** is electrically connected to one or more of the contacts **115**, **215** (block **905**). Thus, the contacts **115**, **215** may provide means for electrically connecting the light emitting device **108**, **208** with other circuitry by forming an electrical connection on the front face of **107**, **207** of the substrate **105**, **205**. An additional connection, or the connection referenced at block **905**, may be formed by attaching a wire bond electrically connecting a respective light emitting device **108**, **208** to a contact portion of the substrate **105**, **205** (i.e. the contact portion may be one of the front side contacts **115**, **215**) (block **910**).

In various embodiments, the substrate **105**, **205** may be a ceramic substrate, a metal core printed circuit board (MCPCB), a flexible circuit substrate and/or a lead frame or the like. Furthermore, one or more light emitting devices **108**, **208** and front side contacts **115**, **215** may be provided in various respective arrangements on the substrate **105**, **205** in different embodiments of the present invention. Removal of residual coating from the contacts as needed may be provided based upon a pattern suited to correspond to the selected geometry or arrangement of light emitting devices and front side contacts in various embodiments of the present invention.

As shown in FIG. **9**, a mask **230** is provided covering the front side contacts **115**, **215** (block **915**). The mask may be, for example, a polyimide film. The substrate is compression molded to form an optical element **110**, **620** on the front face of the substrate **107**, **207** over respective ones of the semiconductor light emitting devices **108**, **208** and a residual coating over a region of the front face of the substrate including the contacts as will now be described with reference to block **920-940**.

As seen in the illustrated embodiments of FIG. **9**, compression molding includes providing a release layer **310** on a surface of the mold **305** including a plurality of lens shaped cavities **320** positioned proximate corresponding ones of the plurality of semiconductor light emitting devices **108**, **208** (block **920**). The substrate is placed in the mold **305** with the cavities positioned proximate corresponding ones of the semiconductor light emitting devices (block **925**). Silicone layer **315** is provided in the mold **305** and the cavities **320** as well as a region between and around the cavities **320** (block **930**). The lenses **620**, **110** are compression molded from the silicone in the cavities (block **935**). The substrate, with a lens formed therein, is removed from the mold (block **940**).

Operations related to removing the residual coating over the contacts without damaging the contacts will now be described for some embodiments of the present invention with reference to blocks **945** and **950** of FIG. **9**. The residual coating is cut in a pattern corresponding to the mask applied as described at block **915** above (block **945**). In some embodiments where the substrate includes a plurality of light emitting devices and contacts on the front face, cutting the residual coating includes cutting the residual coating with a hot knife. The hot knife may have a pattern corresponding to the pattern cut in the residual coating so that the cutting operation may be provided by the advancement of the cutting knife towards the substrate without lateral movement of the cutting member across the substrate. As such, the risk of any damage to the contact surface during the removal process may be reduced. The mask and the cut, overlying residual coating thereon are removed to expose the front side contacts (block **950**).

In some embodiments of the present invention, the light emitting device **108**, **208** is electrically connected to a contact portion by a wire bond before compression molding of the optical element **110**, **620**. Furthermore, in some embodiments, the substrate is compression molded to form the optical element **110**, **620** over the semiconductor light emitting device **108**, **208** and directly contacting the wire bond. A compression molding process as described herein may allow such direct contact and formation of the optical element on both the wire bond and the associated light emitting device while reducing or even preventing damage to the coupling between the light emitting device and the contact portion by the wire bond. In contrast, various other methods of forming a lens of such an arrangement may require the use of additional protective applications so as to avoid damaging the connection between the wire bond and the light emitting device and the corresponding contact portion of a substrate.

Furthermore, in some embodiments of the present invention as described herein, the light emitting device may be mounted flush on the front face of the substrate and a compression molded optical element may be formed around the light emitting device in a dome extending over a full 180 degrees over the light emitting device. As such, a greater flexibility and/or efficiency in extraction and provision of light from the light emitting device may be provided through selection of the lens forming material and any additives or the like added thereto as contrasted with approaches requiring the use of a cavity of a reflective material surrounding the light emitting device. Such reflective cavities generally absorb at least some amount of the emitted light, while a lens or other optical element extending from the front face to fully surround the light emitting device mounted flush on the front face of the substrate may provide improved light extraction in various applications. However, in some embodiments, the LED could reside in a cavity or recess.

While embodiments of the present invention using a mask have been described with reference to FIGS. **3-6** and **9**, it will be understood that some embodiments of the present invention do not use such a mask and cutting process. In some embodiments of the present invention, the substrate is a flexible circuit substrate and the residual coating is removed by a wet solvent chemical cleaning of the substrate to remove the residual coating over the contacts. It will be understood that, whether a mask or wet etching approach is used, the residual coating may be removed over a region of the front face of the substrate including the plurality of contacts but need not completely expose the contacts. However, a sufficient area of the contacts should be exposed to allow making of an electrical connection thereto without residual coating interfering with the electrical connection. A masking approach provided after formation of the residual coating, as contrasted to prior to compression molding, may be used in connection with the wet solvent chemical cleaning operation so as to limit removal of residual coating from desired areas in a selected pattern.

Packaged semiconductor light emitting devices according to further embodiments of the present invention will now be described with reference to the embodiments of FIGS. **7** and **8**. Each include a plurality, illustrated as first and second, of optical elements formed on a substrate. It will be understood that one and/or both of the respective optical elements may be formed using compression molding in different embodiments of the present invention.

As seen in the embodiments of FIG. **7**, a packaged semiconductor light emitting device **700** includes a plurality of semiconductor light emitting devices **708** mounted flush on a front face **707** of a substrate **705**. A first optical element **740** is formed over each of the semiconductor light emitting devices **708**. A second optical element **720** is formed over the first optical element **740** and the light emitting device **708**. As further shown in the embodiments of FIG. **7**, an additive **742** may be added to the second optical element **720** to affect the light transmission or emission characteristics of the semiconductor light emitting device **708**. It will be understood that the additive **742** may instead be added to the first optical element **740** or a same and/or different additive may be provided in each of the optical elements **720**, **740**. In addition, optical properties may be further tailored by selection of different characteristics for the respective optical elements **720**, **740**, for example, selecting a different refractive index for the respective materials to provide a desired effect in passage of light emitting from the semiconductor light emitting device **708**. Additives to affect optical properties may include a phosphor, a scatter agent, a luminescent material and/or other material affecting optical characteristics of the emitted light.

It will be understood that both the first and second optical elements may be compression molded in the embodiments of FIG. **7**. However, in further embodiments, the first optical element **740** may be formed by other means and the second optical element **720** may be formed by compression molding generally as described above with reference to FIGS. **3-6** and FIG. **8**.

Further embodiments of a packaged semiconductor light emitting device **800** are illustrated in FIG. **8**. As seen in the embodiments of FIG. **8**, a semiconductor light emitting device **808** is mounted flush on a front face of a substrate **805**. A wire bond **809** is shown making a connection between the substrate **805** and the semiconductor light emitting device **808**. While not seen in FIG. **8**, it will be understood that a second connection may be formed at the interface between the light emitting device **808** and the front face of the substrate **805**.

A first optical element **840** is formed proximate a light emitting device **808** on the front face of the substrate **805**. A second optical element **820** is formed over the light emitting device **808**, the wire bond **809** and the first optical element **840**. As described with reference to FIG. **7**, one or both of the respective optical elements **840**, **820** may be formed by compression molding generally as described previously herein. Furthermore, the first optical element **840**, while appearing as two discrete elements in the cross sectional view of FIG. **8**, may be a toroidal shaped single optical element extending around the light emitting device **808** and wire bond **809**.

Further embodiments of methods for forming a packaged semiconductor light emitting device will now be described with reference to the flowchart illustration of FIG. **10**. More particularly, the methods described with reference to FIG. **10** may be used in forming the devices illustrated in FIG. **7** or FIG. **8**. For purposes of the description of FIG. **10**, embodiments in which both the optical elements are compression molded in an automated molding apparatus will be described. However, it will be understood that the invention is not limited to such embodiments. Furthermore, it will be understood the operations as described with reference to compression molding may be used in some embodiments with the substrate having contacts on a front face thereof and removal of a residual portion of the molding material to expose the front face contacts as described previously herein.

For the embodiments illustrated in FIG. **10**, operations begin with providing a substrate having a semiconductor light emitting device on a front face thereof (block **1000**). As discussed previously, the substrate may include a plurality of semiconductor light emitting devices on the front face thereof, such as illustrated in FIGS. **1** and **2**. Furthermore, the semiconductor light emitting devices may be mounted flush on the front face of the substrate without a reflector cavity. The substrate may be, for example, a ceramic substrate, a MCPCB, a flexible circuit substrate and/or a lead frame. However, the light emitting devices may be mounted in a reflector cavity or the like.

Operations related to forming first and second optical elements of the packaged semiconductor light emitting device will now be described with reference to blocks **1005-1030**. The substrate is loaded in an automated molding apparatus including a first mold cavity configured to form the first optical element and a second mold cavity configured to form the second optical element (block **1005**). The first and second mold cavities may each include a plurality of lens shaped cavities positioned proximate corresponding ones of the plurality of semiconductor light emitting devices where the substrate includes a plurality of semiconductor light emitting devices thereon. The substrate is moved to the first mold cavity (block **1010**). The movement may be by automated conveyor, robotic arm and/or the like within the automated molding apparatus.

The first optical element is compression molded on the front face of the substrate in the first mold cavity (block **1015**). It will be understood that, while shown as compression molding at block **1015**, the first optical element or the second optical element may be formed using a process other than compression molding, such as dispensing and/or bonding. Furthermore, the first optical element may be formed at block **1015** proximate the semiconductor light emitting device but not covering the semiconductor light emitting device as illustrated, for example, by the optical element **840** in FIG. **8**. The first optical element may also in some embodiments be formed at block **1015** molded to and extending from the front face of the substrate in a region surrounding the semiconductor light emitting device and extending over the semiconductor light emitting device as shown for the first optical element **740** in the embodiments of FIG. **7**. In some embodiments, where the first optical element does not extend over the light emitting device, the first optical element may be shaped to define a cavity with the semiconductor light emitting device positioned in the cavity.

The substrate with the first optical element thereon is moved to the second mold cavity without requiring removal of the substrate from the automated molding apparatus (block **1020**). For example, a conveyor or robotic tool, such as described with reference to operations at block **1010**, may also be used for operations at block **1020**.

The second optical element is compression molded in the second optical cavity (block **1025**). As described with reference to the first optical element illustrated in FIG. **8**, the second optical element may be molded to extend from the front of the substrate in a region surrounding the semiconductor light emitting device and extend over the light emitting device as seen with the second optical element **720** in FIG. **7** and the second optical element **820** in FIG. **8**. The substrate with the first and second optical elements thereon is removed from the automated molding apparatus (block **1030**).

As also seen in both FIG. **7** and FIG. **8**, the second optical element may be compression molded over both the semiconductor light emitting device and the first optical element. The first optical element and the second optical element may have different refractive indexes selected to provide a desired optical characteristic for the packaged semiconductor light emitting device. The first and second optical element may be configured to provide a selected viewing angle to the packaged semiconductor light emitting device. In some embodiments, the material used in forming the first and/or second optical element has an adhesion characteristic selected to facilitate adhesion of the first optical element to the substrate during compression molding and/or to limit stress applied to the light emitting device and/or a wire bond coupled thereto during thermal cycling of the packaged semiconductor light emitting device. The first optical element material and/or the second optical element material may include a phosphor. The first material and/or the second material may be silicone, epoxy, a hybrid silicone/epoxy material and/or the like.

As described above, some embodiments of the present invention provide packaged semiconductor light emitting devices and methods for forming the same using compression molding to produce lens having tailored optical properties. For example, light emitting devices packaged with composite lenses produced using compression molding may be provided. In some embodiments, multiple compression molds may be used to produce compression molded lenses where both the first and the second optical elements are compression molded to produce lenses having desired optical properties, such as viewing angles. In other embodiments, a first optical element may be dispersed, bonded or the like and the second optical element may be compression molded. As such, the first and second optical elements may have different properties (shape, composition, refractive index, and so on) tailored to the needs of the application of the packaged device. Some embodiments may also include additional optical elements, layers and/or compression molds in addition to the first and second optical element. Furthermore, the shape and composition of each optical element may be different from one another and may be tailored to provide a desired lamp performance. Improved adherence and/or lower stress on compliant parts may be provided in various embodiments of the present invention

In the drawings and specification, there have been disclosed embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.

What is claimed is:

1. A method of packaging a semiconductor light emitting device, comprising:

providing a substrate having the semiconductor light emitting device on a front face thereof and a contact on the front face thereof, wherein the light emitting device is electrically connected to the contact on the front face of the substrate;

providing a mask covering a first portion of the contact, wherein a second portion of the contact is free of the mask;

compression molding an optical element on the front face of the substrate over the semiconductor light emitting device and a residual coating over a region of the front face of the substrate including the contact, including applying heat to cure the optical element and residual coating; and

removing the residual coating and the mask from the first portion of the contact without damaging the contact to form a compression molded lens that covers the semiconductor light emitting device and the second portion of the contact.

2. The method of claim **1**, wherein providing a substrate comprises:

mounting the semiconductor light emitting device on the front face of the substrate; and

attaching a wire bond electrically connecting the semiconductor light emitting device to a contact portion of the substrate.

3. The method of claim **2**, further comprising mounting a second semiconductor light emitting device on a back face of the substrate and electrically connecting the second semiconductor light emitting device to a contact on the back face of the substrate.

4. The method of claim **2**, wherein compression molding comprises compression molding the substrate to form the optical element over the semiconductor light emitting device and the wire bond and directly contacting the wire bond.

5. The method of claim **1**, wherein the substrate comprises a ceramic substrate, a metal core printed circuit board (MCPCB), a flexible circuit substrate and/or a lead frame.

6. The method of claim **1**, wherein the mask comprises a polyimide film.

7. The method of claim **1**, wherein removing the mask comprises:

cutting the residual coating in a pattern corresponding to the mask; and

removing the mask and the overlying residual coating thereon to expose the front side contact.

8. The method of claim **1**, wherein the substrate comprises a flexible circuit substrate and wherein removing the residual coating comprises wet solvent chemical cleaning the substrate to remove the residual coating over the contact.

9. The method of claim **8**, wherein the substrate includes a plurality of semiconductor light emitting devices and contacts on the front face thereof and wherein compression molding the substrate comprises compression molding the substrate to form a plurality of optical elements on the front face of the substrate over corresponding ones of the semiconductor light emitting devices and a residual coating over a region of the front face of the substrate including the plurality of contacts.

10. The method of claim **9**, wherein the optical elements comprise lenses and wherein compression molding comprises:

placing the substrate in a mold including a plurality of lens shaped cavities positioned proximate corresponding ones of the plurality of semiconductor light emitting devices;

providing silicone into the mold;

compression molding the lenses from the silicone in the cavities; and

removing the substrate with the lenses formed therein from the mold.

11. The method of claim **1**, wherein the optical element comprises a first and a second optical element and wherein compression molding comprises:

compression molding the first optical element proximate the semiconductor light emitting device; and

compression molding the second optical element over the semiconductor light emitting device and the first optical element.

12. The method of claim **11**, wherein compression molding the first optical element comprises compression molding the first optical element over the semiconductor light emitting device.

13. The method of claim **1**, wherein the optical element comprises a second optical element and wherein compression molding is preceded by forming a first optical element proximate the semiconductor light emitting device and wherein compression molding the substrate comprises compression molding the second optical element over the semiconductor light emitting device and the first optical element.

14. The method of claim **1**, wherein the optical element comprises a first optical element and wherein compression molding is followed by forming a second optical element over the semiconductor light emitting device and the first optical element.

15. The method of claim **1**, wherein compression molding comprises applying the heat of at least 100° C. for a time of at least 3 minutes at a pressure of at least 0.1 tons/in^2.

16. The method of claim **1**, wherein the contact is adjacent the semiconductor light emitting device, the first portion of the contact is distal from the semiconductor light emitting device and the second portion of the contact is proximal to the semiconductor light emitting device.

17. The method of claim **1**, wherein the semiconductor light emitting device comprises a first semiconductor light emitting device, wherein the substrate includes a second semiconductor light emitting device on the front face thereof, and wherein removing the residual coating comprises removing the residual coating from between the first semiconductor light emitting device and the second semiconductor light emitting device.

18. The method of claim **17**, wherein the mask is on the substrate between the first and second semiconductor light emitting devices, and wherein removing the residual coating from between the first semiconductor light emitting device and the second semiconductor light emitting device comprises removing the mask from between the first semiconductor light emitting device and the second semiconductor light emitting device.

19. A method of packaging a plurality of semiconductor light emitting devices, comprising:

providing a substrate having the plurality of semiconductor light emitting devices and a plurality of contacts on a front face thereof, wherein the plurality of light emitting devices are electrically connected to the plurality of contacts on the front face of the substrate;

providing a mask covering the front side plurality of contacts;

compression molding a plurality of optical elements on the front face of the substrate over the plurality of semiconductor light emitting devices and a residual coating over a region of the front face of the substrate including the plurality of contacts, including applying heat to cure the plurality of optical elements and residual coating;

removing the residual coating over at least a portion of the plurality of contacts without damaging the plurality of contacts by cutting the residual coating in a pattern corresponding to the mask, wherein cutting the residual coating comprises cutting the residual coating with a hot knife, the hot knife having a two-dimensional pattern corresponding to the pattern cut in the residual coating and wherein cutting the residual coating comprises cutting the residual coating with a single direction motion of the hot knife into the residual coating; and

removing the mask and the overlying residual coating thereon to expose the plurality of front side contacts.

20. The method of claim **19**, wherein the optical elements comprise lenses and wherein compression molding comprises:

placing the substrate in a mold including a plurality of lens shape cavities positioned proximate corresponding ones of the plurality of semiconductor light emitting devices;

providing silicone into the mold;

compression molding the lenses from the silicone in the cavities; and

removing the substrate with the lenses formed therein from the mold.

21. The method of claim **20**, wherein providing silicone is preceded by providing a release layer on a surface of the mold including the cavities and wherein removing the substrate comprises removing the substrate at the release layer.

22. A method of packaging a semiconductor light emitting device, comprising:

providing a substrate having the semiconductor light emitting device on a front face thereof and a contact on the front face thereof, wherein the light emitting device is electrically connected to the contact on the front face of the substrate;

compression molding an optical element on the front face of the substrate over the semiconductor light emitting device and a residual coating over a region of the front face of the substrate including the contact, including applying heat to cure the optical element and residual coating; and

removing the residual coating over at least a portion of the contact without damaging the contact by cutting, with a single direction motion, into the residual coating with a hot knife having a two-dimensional pattern.

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